AERONAUTICAL RESEARCH AND THE ART OF AIRPLANE DESIGN

Hugh L. Dryden
Director, National Advisory Committee for Aeronautics

(For presentation at joint meeting of the Canadian Aeronautical Institute and the Institute of Aeronautical Sciences, Montreal, Canada, October 14, 1954.)

Twenty-two years ago tomorrow the Institute of the Aeronautical Sciences was incorporated for the purpose, among others, of advancing the art and science of aeronautics. At the Founders' Day Meeting in January of the next year E. P. Warner gave a brief talk on "The Application of Science to Design". According to the printed abstract, he dealt with the status of airplane design and with the question of the extent to which it could be made rigorously subordinate to scientific rules. He asserted that while practical airplane design was an art, pure science had been steadily encroaching upon the ground of "engineering judgment". He suggested that it would be a good thing for every engineering staff to have at least one member whose sole duty it would be to keep abreast of advances in aerodynamic theory, and in the theory of structures. This individual should press their possible practical applications constantly upon the attention of his superiors on the staff.

General James H. Doolittle had a few months before returned the land plane speed record to the United States by flying his racing airplane at 296.287 miles per hour. Our technical progress since then may be measured by the events of last December when Major Charles Yeager attained a speed of about 1650 miles per hour in a research airplane. During the past year several tactical military airplanes demonstrated their ability to fly faster than sound in level flight. This remarkable increase in performance has been accomplished by the "steady encroachment of science upon the ground of engineering judgment". But I believe that there is still an art as well as a science of aeronautics. I wish to discuss briefly the interplay of scientific research and the art of design in aeronautical progress.

The essential difference in outlook between the research scientist and the designer was brought forcibly to my attention by a visit from Sir William Farren after he had made the transformation from research director to airplane designer.

"You know," he said to me, "I envy you research fellows. I come to tell you my troubles. My prototype airplane has a tricky control characteristic and shakes a bit too much and I ask you what I should do. You think a bit, look at your curves, and manipulate your slide rule, and very confidently say to me, 'If I were you I would raise the horizontal tail 3 feet, increase the size of the vertical tail 10 per cent, and make the wing root fairing larger.' I thank you, return home, sweat out the modifications for six months and anxiously await the result of the first test flight. My test pilot tells me that there is no improvement. I report this to you somewhat plaintively a year after my first visit. You tell me, 'I was afraid that those changes might not be effective, especially after we got some more test data after your visit. Too bad. If I were you, I'd move the tail 2 feet lower than it's original position'. What a racket. I can do that kind of guessing myself. The designer's life is a sorry one. I should never have left the Royal Aircraft Establishment". (With apologies to Sir William Farren for inaccurate reporting.)

Research advances knowledge by isolation of limited aspects of development problems which are analyzed by specialists in specific fields. The designer of an airplane or missile must solve all of the many problems in a single integrated prototype. Design is still an art practiced by individuals or groups of individuals in a design team. They must have general knowledge of many fields and the ability to synthesize information from many sources.

A useful airplane like any other accomplishment of the human race is preceded by creative activity in the invisible world of some human mind. The pathway from vision to accomplishment is sometimes long and arduous. For a number of years following the first successful flight it was possible for any individual to learn and know all there was to be known about aeronautics and aircraft design. If equipped with the requisite powers of vision, he might become a successful designer. The situation soon changed. Today it is very difficult to discover the designer of one of our modern airplanes. It is the product of a large organization of many specialists of many types, of a team.

No member of the team has complete knowledge of the final product in all its detail. When you examine this modern airliner you do indeed wonder how any one man could have invented or designed it. Of course no one man did or could. Its development rests on the contributions of many men in the past and of many men now living.

The vision of the designer is guided today not only by the experience and accomplishments of the past but also by the specialized and somewhat artificial type of experience known as scientific research. Modern science seeks to know and understand the laws of Nature -- how air flows around bodies; what forces, pressures, and loads are exerted on bodies moving through the air; how materials and structures behave under load. Such knowledge is the secure foundation on which all engineering accomplishment rests.

The feeding of the results of the experiences of the research worker into the mind of the engineer does not, however, make him a creative designer. The distillation of the discoveries of other men into an engineering handbook may provide sufficient basis for the training of engineers in some fields. But in aeronautics economy of materials and refinement of design are of great importance. Handbook engineers are of no value in aeronautical development today. Likewise mere training in the knowledge and techniques of the aeronautical sciences will not make a good member of an aircraft design team. The art of inventive application must also be mastered, the art of finding new means to old ends, skill in finding new combinations of old elements. Problems must be met not only with correct scientific and technical knowledge but also with ingenuity. Creative activity within the mind of the aircraft designer is the first step along the pathway toward the practical realization of a successful airplane.

The next step is to send out exploring parties, to make forays to verify or modify the intended course. This is the activity of applied research. The questions are now asked of Nature. You recall Boss Kettering's approach of asking the Diesel engine rather than a consulting engineer whether a given design of piston was good or not. The theoretical and conceptual ideas must be given the acid test of actual trial. If the theory proves wrong, if one approach does not make progress toward the goal, the intelligent engineer will seek a new theory or a new approach. In aeronautical development we find need for a great deal of applied research. Some is of a very specific nature directed to limited objectives. Some is of a very general nature directed to broad objectives. The result of all this activity is to establish confidence that the vision is a realizable one, that the <u>foreseen</u> problems can be solved. The unforeseen problems are another and later story.

The scene now reverts to the immaterial sphere of the mind. The problem now is to sharpen the vision to an integrated and coordinated design. Necessary compromises between conflicting requirements must be made.

The solution must be consistent with demonstrated possibilities of achievement. The designer is a creative artist like the architect, who with a given site on a rocky hillside, a given family with certain living habits and needs, and a certain supply of available materials plans a structure which most harmoniously meets the given conditions. Or, the designer is like the composer of a great symphony, who knows the characteristics and capabilities of all of the different instruments and must write the score for all. The result is to be a unified and integrated composition. The success or failure is in the composer's hands and is decided before the orchestra plays a single note.

The symphony orchestra conductor now takes over from the composer; the builder from the architect; the production engineers and artisans from the airplane designer. Their job is to make the vision come true, to turn notes into music, plans into houses, acres of blueprints into a structure of aluminum, steel, and plastic-- an airplane. At every step the same cycle of mental-physical activity is repeated. Each accomplsihment is preconceived in the mind of man and the more creative, the more inventive, the more experienced, and the more intelligent the man who conceives and plans, the more advanced and the more suitable to its purpose is the resulting product.

Now come the unforeseen problems as the user takes over. The new airplane is born not to be set on a pedestal to be admired for its beauty, for the complexity of its construction, or for its cost. It was made to serve a purpose; it is a tool to accomplish the purposes of man, in transporting him and his possessions, or in fighting his enemies. The infant airplane moves out of the factory to the flying field. It is rained on, hailed on, frozen and scorched, pounded by gusts and hard landings. The process of evaluation and further development to overcome shortcomings begins. This is the life cycle of a new airplane.

During the life of the Institute of the Aeronautical Sciences we have seen aircraft design expand from the solo effort of the inventor to the symphony of the team. It seems to me that we are in an era in which even this latter concept is inadequate. After all, the score of the symphony can be broken down into separate scores for each instrument. A coordination is necessary as regards time, melody, and harmony but this can readily be accomplished because the details of the score for each instrument can be worked out, once the general structure of the composition is given, with little interference or interaction.

Prior to World War II the design problems of an airplane could be readily broken down into aerodynamic problems, power plant problems, structural problems, electrical problems, hydraulic problems, etc. Each group could work out the optimum solution from its own specialized point of view with comparatively little interference. The most necessary coordination was a purely dimensional one. Space must be available as required. Mating parts must fit and operate without mechanical interference. There were of course a few problems of a different nature such as the effect of the propeller slipstream on the stability and control of the airplane. This problem required consideration and optimization of the mutual effects by the propeller and stability groups. Similarly the drag associated with cooling required joint study by the power plant and aerodynamics groups. As speeds increased, the aerodynamicist began to complain of the many crude excrescences demanded by the electronics group for radio and radar antennae. As structural design was refined, the mutual effects of aerodynamic loads on structural deflection and of structural deflection on aerodynamic loads introduced borderline problems of flutter and aeroelasticity. Modern power plants swallow so much air that the separation of thrust from drag becomes almost a matter of definition. The interaction between power plant and flow around the airframe is so great that experiments on the whole configuration with operation of the power plant present or simulated become almost indispensable. High speeds show up the limitations of the human body as a servomechanism for responding to stimuli, and a whole new science of automatic control of aircraft is being born.

In all of these cases the mutual interactions are large and a functional coordination is required. New methods for systems analysis must be devised. Complexities of a new type are introduced. The problem differs from one which involves merely the pyramiding of a large number of similar elements as one does in building a large apartment house as compared with building a single house. Their only difference is in the number of bricks and workmen required. In the past the building of a large aircraft differed from that of building a small one only in that many more people were required to do the detail design of many more joints and pieces. The building of a modern high speed aircraft or missile today requires a new concept of team activity and functional coordination, and a team consisting of more kinds of specialists with knowledge of more scientific fields. The apparent slowness of guided missile development stems from these new requirements. The teams had to be assembled and learn to work together. They had to learn the nature of the intricate problems and methods for their solution by actual experience. They had to develop methods of system analysis and to overcome unforeseen problems.

The development of the art of airplane and missile design to its present state, would have been impossible without the accompanying advance in scientific research and the utilization of the results by the designer. Research has also progressed from the unrelated investigations of a comparatively few individuals on subjects which interested them. We now have the organized effort of large groups on programs whose goals are set by the joint thinking of university scientists, research staff, aircraft designers and aircraft users. It is the collaboration of scientist, designer, and user which has made present-day aeronautical research so fruitful and permitted such a rapid rate of progress.

It has become necessary to achieve a more satisfactory integration of the efforts of research scientists and designers than that pictured in the Farren story. We who are engaged in research are pleased by the manner in which our collaboration with the design teams responsible for many current prototype aircraft is being recognized by the members of those design teams as an important element in the success of their new aircraft. And today the performance of the new prototypes underlines the accuracy of predictions drawn from the wind tunnel and other research data. Conversely, today's research workers have a keener understanding of the designer's task. Perhaps also, they have a more intimate awareness of his responsibilities in the aircraft development process.

There is no sign of a limit to aircraft development or to the ever-widening horizons of aeronautical research. The sonic barrier has been found to be less formidable than anticipated. Before us lie the problems of still higher speeds and altitudes, aerodynamic heating, complex structural problems, difficult stability and control problems in the thin upper air. The same collaboration of scientist and designer which has multiplied the speed more than 5 times in 22 years will solve these new problems.

In conclusion, there is still both art and science in aeronautics. The design of aircraft will never be "rigorously subordinate to scientific rules". But without a steady increase in scientific knowledge the art of aircraft design would become stagnant, supported by a vigorous scientific activity in aeronautical research, the art of design will flourish.

Actual and possible accomplishments will expand and visions, hitherto unrealizable, will become practical engineering projects.